APPENDIX

E Driven Piles

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Four commonly used pile driving formulas are the ENR, the JANBU, the HILEY, and the PACIFIC COAST. They are described on the following pages. These are offered to show the differences in complexity and approach used by their authors. The formula description is followed by examples used to illustrate how results will differ depending on the formula used.

PILE DRIVING FORMULAS

ENGINEERING NEWS (ENR)

$P = 2E/(s + 0.1)$

where: P = safe load in pounds

E = rated energy in foot-pounds

s = penetration per blow in inches

This formula was derived from the original Engineering News formula for drop hammers on timber piles, which was $P = W\ H\ /\ (s + c)$

W = weight of ram in pounds

H = length of stroke in inches

c = elastic losses in the cap, pile, and soil in inches.

It was modified to correct units and apply other factors to compensate for modern equipment.

JANBU FORMULA

$$P = \frac{W\ H}{k_u s} \times Z$$

where: P = safe load in pounds

W = weight of ram in pounds

H = length of stroke in inches

s = penetration per blow in inches

k_u = factor derived from the following:

$$k_u = C_d \left[1 + \sqrt{1 + \frac{\lambda}{C_d}}\right]$$

$$C_d = 0.75 + 0.15\,\frac{W_p}{W}$$

$$\lambda = \frac{W\ H\ L}{A\ E\ s^2}$$

when: W_p = weight of pile in pounds

L = length of pile in inches

A = area of pile in sq. in.

E = modulus of elasticity of pile in psi

Z = conversion factor for units and safety with this formula.

HILEY FORMULA

$$P = \frac{e_f\ W\ H}{s + \frac{1}{2}\,(c_1 + c_2 + c_3)} \times \frac{W + n^2\,W_p}{W + W_p} \times Z$$

where: P = safe load in pounds

e_f = efficiency of hammer (%)

W = weight of ram in pounds

H = length of stroke in inches

s = penetration per blow in inches

c_1, c_2, c_3 = temporary compression of pile cap and head, pile, and soil, respectively in inches

n = coefficient of restitution

W_p = weight of pile in pounds

Z = conversion factor for units and safety with this formula

PACIFIC COAST FORMULA

$$P = \frac{E_n\ \dfrac{W + k\,W_p}{W + W_p}}{s + \dfrac{PL}{AE}} \times Z$$

where: P = safe load in pounds

E_n = energy of driving in inch-pounds

W = weight of ram in pounds

W_p = weight of pile in pounds

s = penetration per blow in inches

L = length of pile in inches

A = area of pile in sq. in.

E = modulus of elasticity of pile in psi

k = 0.25 for steel piles

0.10 for other piles

Z = conversion factor for units and safety with this formula

COMPARISON OF FORMULAS

Problem Conditions:

Hammer: Delmag 30 E_m = 66,100 ft-lbs

Ram Weight = 6,600 lbs

Max. Stroke = 10 ft

Set or Penetration = 0.844 inches

Length of pile = 80 feet

Assume hard driving

Case 1 : 12" PC/PS Concrete Pile

Case 2 : 12 BP 53 Steel Pile

Engineering News Formula

For both piles: $P = 2E/(s + 0.1)$

$= 2 \times 66100/(0.844 + 0.1)$

$= 70$ tons

Janbu Formula

Case 1:

$$P = \frac{WH}{k_u s} \times \frac{1}{3 \times 2000}$$

$$= \frac{6600(10\times12)}{3.034(.844)} \times \frac{1}{3 \times 2000}$$

$$= \frac{309290}{3 \times 2000}$$

$$= 51.5 \text{ tons}$$

$$C_d = 0.75 + 0.15\, W_p / W$$

$$= 0.75 + 0.15(11850)/6600$$

$$= 1.019$$

$$\lambda = \frac{W H L}{A E s^2}$$

$$= \frac{6600\ (10 \times 12)\ (80\times12)}{144\ (2.5 \times 10^6)(.844)^2}$$

$$= 2.965$$

$$k_u = C_d\left[1 + \sqrt{1 + \lambda / C_d}\right]$$

$$= 1.019\left[1 + \sqrt{1 + \frac{2.965}{1.019}}\right]$$

$$= 3.034$$

Case 2:

$$P = \frac{WH}{k_u s} \times \frac{1}{3 \times 2000}$$

$$= \frac{6600\ (10\times12)}{2.473\ (.844)} \times \frac{1}{3 \times 2000}$$

$$= \frac{379450}{3 \times 2000}$$

$$= 63.2 \text{ tons}$$

$$C_d = 0.75 + 0.15\ (4240)/6600$$

$$= 0.846$$

$$= \frac{6600\ (10\times12)\ (80\times12)}{15.58\ (30 \times 10^6)\ (.844)^2}$$

$$= 2.284$$

$$k_u = 0.846\left[1 + \sqrt{1 + \frac{2.284}{0.846}}\right]$$

$$= 2.473$$

HILEY FORMULA:

Case 1: $$P = \frac{e_f\ W\ H}{s + (c_1 + c_2 + c_3)} \times \frac{W + n^2 W_p}{W + W_p} \times \frac{1}{2.75 \times 2000}$$

$$= \frac{1.00(6600)(10 \times 12)}{0.844 + ½(.37+.32+.10)} \times \frac{6600 + 0.25^2(11850)}{6600 + 11850} \times \frac{1}{2.75 \times 2000}$$

$$= \frac{254300}{2.75 \times 2000} = 46.2 \text{ tons}$$

Case 2: $$P = \frac{1.00(6600)(10 \times 12)}{0.844 + ½(0.0+.48+.10)} \times \frac{6600+4240(.55)^2}{6600 + 4240} \times \frac{1}{2.75 \times 2000}$$

$$= \frac{507900}{2.75 \times 2000} = 92.3 \text{ tons}$$

PACIFIC COAST FORMULA:

Case 1: $$P = \frac{E_n \dfrac{W + k W_p}{W + W_p}}{s + \dfrac{P L}{A E}} \times \frac{1}{4 \times 2000}$$

$$= \frac{66100(12) \times \dfrac{6600 + 0.1(11850)}{6600 + 11850}}{0.844 + \dfrac{P (80 \times 12)}{144 (2.5 \times 10^6)}} \times \frac{1}{4 \times 2000}$$

$$= \frac{334690}{0.844 + .0000027P} \times \frac{1}{4 \times 2000}$$

$$= \frac{228940}{4 \times 2000} = 28.6 \text{ tons}$$

Case 2:

$$P = \frac{66100(12) \times \dfrac{6600 + 0.25(4240)}{6600 + 4240}}{0.844 + \dfrac{P (80 \times 12)}{15.58 (30 \times 10^6)}} \times \frac{1}{4 \times 2000}$$

$$= \frac{560508}{0.844 + .0000021P} \times \frac{1}{4 \times 2000}$$

$$= \frac{353420}{4 \times 2000} = 44.2 \text{ tons}$$

TABULATION OF COMPARISON RESULTS

FORMULA	CASE 1	CASE 2
	12" PC/PS	12 BP 53
Pile Length = 80 feet		
ENR	70 tons	70 tons
JANBU	51	63
HILEY	46	92
PACIFIC COAST	28	44
Pile Length = 40 feet		
ENR	70 tons	70 tons
JANBU	67	77
HILEY	65	106
PACIFIC COAST	44	61

Example Calculation Minimum Hammer Energy

GIVEN:

Bearing Capacity = 70 tons

Proposed Hammer is Delmag 30-23

Manufacturer's Maximum Energy Rating 66,100 ft-lbs

CHECK HAMMER ENERGY, PER (SECTION 49-1.05)

FROM THE ENR EQUATION, $$P = \frac{2 * E}{(S + 0.1)}$$

REARRANGING $$S = \frac{2 * E}{P} - 0.1$$

PLUG IN GIVEN VALUES $$S = \frac{2 * 66{,}100}{140{,}000} - 0.1 = 0.84 \text{ in.} > .125 \text{ in.}$$

THE HAMMER MEETS THE ENERGY REQUIREMENTS OF SECTION 49-1.05.

Example Calculation Blow Count Chart

GIVEN:
BEARING CAPACITY = 70 TONS

PROPOSED HAMMER IS DELMAG 30–23

HAMMER WEIGHT = 6,600 lbs.

ASSUME E = HAMMER WEIGHT X STROKE

USING ENR EQUATION $P = \frac{2 * E}{(S + 0.1)}$

REARRANGE $S = \frac{2 * E}{P} - 0.1$

UNITS FOR S ARE INCHES PER BLOW

CONVERT S TO FEET PER BLOW

$$\frac{S * 1\ ft}{12\ in} = \frac{FT}{BLOW}$$

$$\frac{S}{1} = \frac{2 * E}{P} - 0.1$$

INVERTING THE EQUATION TO GET BLOWS PER FOOT

$$S = \frac{12}{(2 * E/P - 0.1)}$$

EXAMPLE: ASSUME A 9 FOOT STROKE FOR THE GIVEN HAMMER

E = 9 * 6,600 lbs = 59,400 ft_lbs

S = 12 / ((2 * 59,400 / 140000) – 0.1) = 16 BLOWS PER FOOT

CONTINUE CALCULATIONS FOR VARYING STROKE HEIGHT

Example Blow Count Chart

PILE BLOW DATA

job stamp

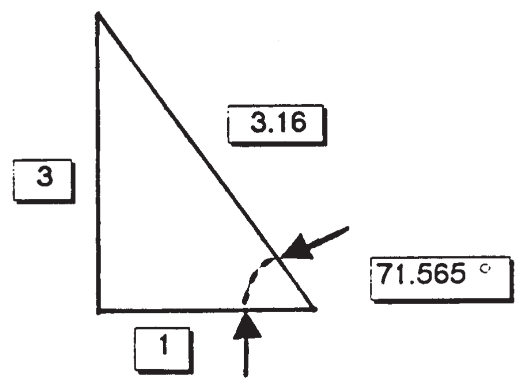
PILE CAPACITY	140000	POUNDS
HAMMER	D 30-23	
PISTON WEIGHT	6,600	POUNDS

stroke (feet)	reqd. blows	stroke (feet)	reqd. blows
10	14	7.0	21
9.5	15	6.5	23
9	16	6	26
8.5	17	5.5	29
8	18	5	32
7.5	20	4.5	37

Example Battered Pile Blow Count Chart

BATTERED PILE

PILE CAPACITY 140000 POUNDS
HAMMER D 30-23
PISTON WEIGHT 6,600 POUNDS



E = W * H * SIN 71.565 °

STROKE FEET	BLOW S PER FOOT
10	15.0
9.5	15.9
9	16.9
8.5	18.0
8	19.3
7.5	20.8
7	22.6
6.5	24.6
6	27.1
5.5	30.2
5	34.0

Example Calculation Timing of Single Acting Hammer

ACCELERATION $= 32.2$ ft / sec^2

VELOCITY $= 32.2$ ft / sec^2 * T sec

DISTANCT $= 32.2$ ft / sec^2 * $\dfrac{T\text{ ^2}}{2}$

$$= \frac{g * T\text{^2}}{2}$$

WE ASSUME THAT $T_{fall} = T_{whole} / 2$

THE EQUATION BECOMES DISTANCE $= \dfrac{g}{2} * \dfrac{(Twhole)\text{^2}}{(2\text{^2})}$

WHICH BECOMES DISTANCE $= \dfrac{g * T\text{ ^2}}{8}$

PLUG IN 32.2 FOR g DISTANCE = 4.02 * T ^2

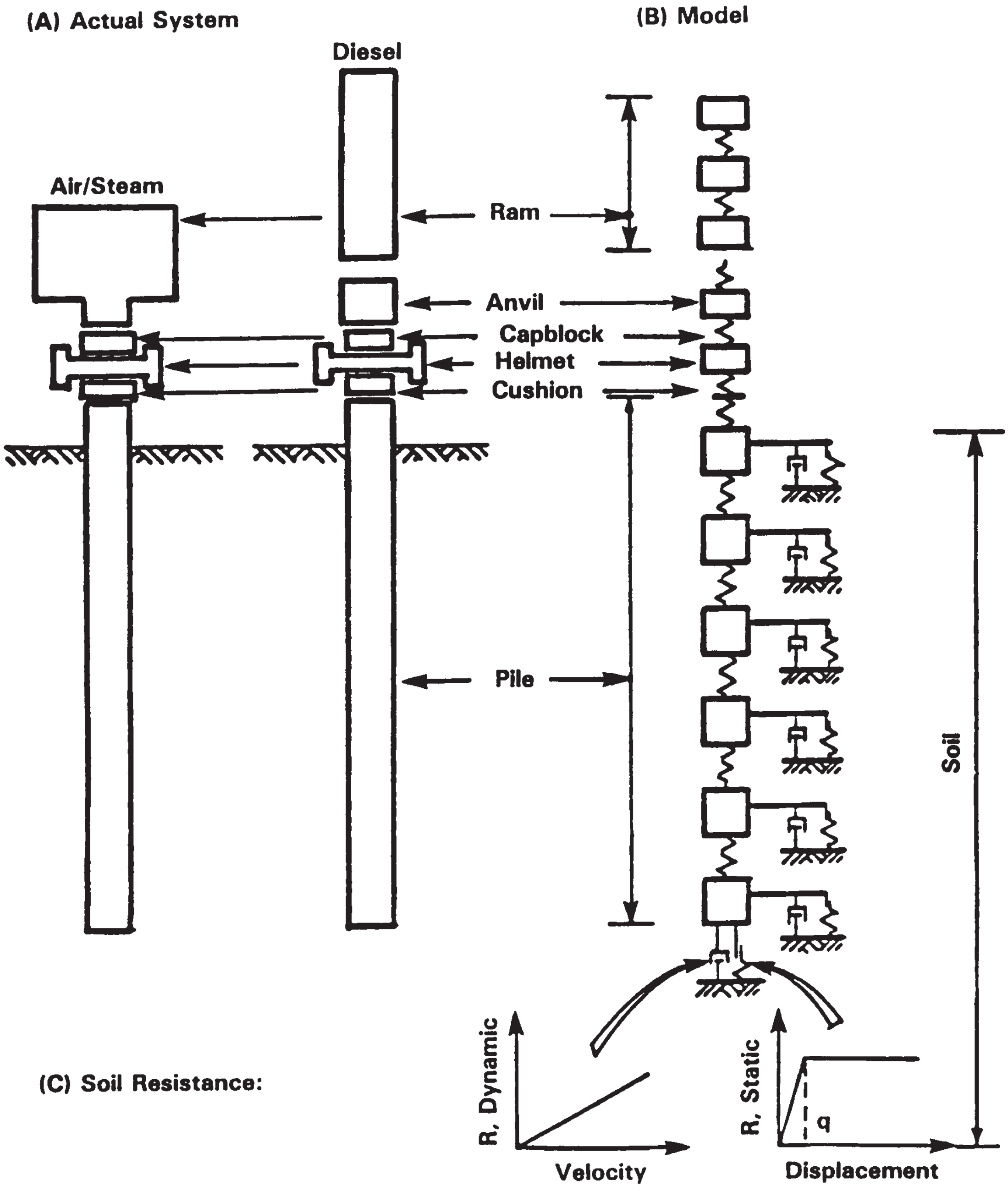
A CORRECTION OF MINUS 0.3 WAS ADDED FOR CORRELATION TO FIELD MEASURED VALUES.

DISTANCE = 4.02 * T ^2 – 0.3

Example Pile Pick Calculation

This section was not available at the time of publication.

Example Wave Equation Model



WAVE EQUATION MODEL
(A) THE SYSTEM TO BE ANALYZED; (B) THE WAVE EQUATION MODEL; AND (C) THE COMPONENTS OF THE SOIL RESISTANCE MODEL

Example Wave Model and Output

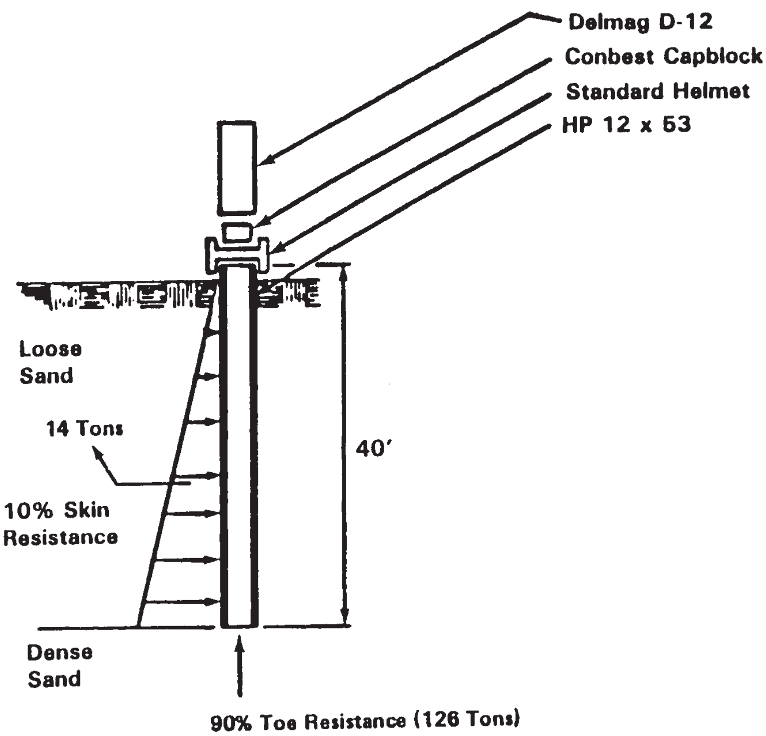
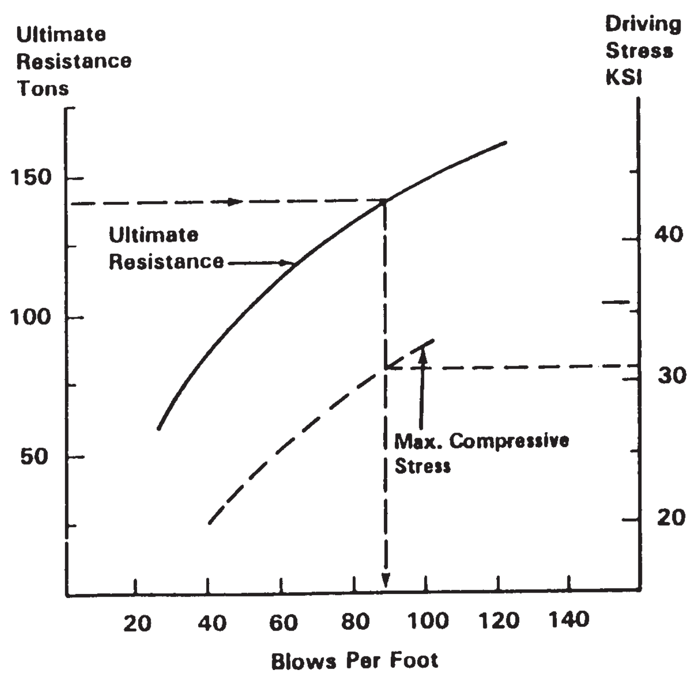
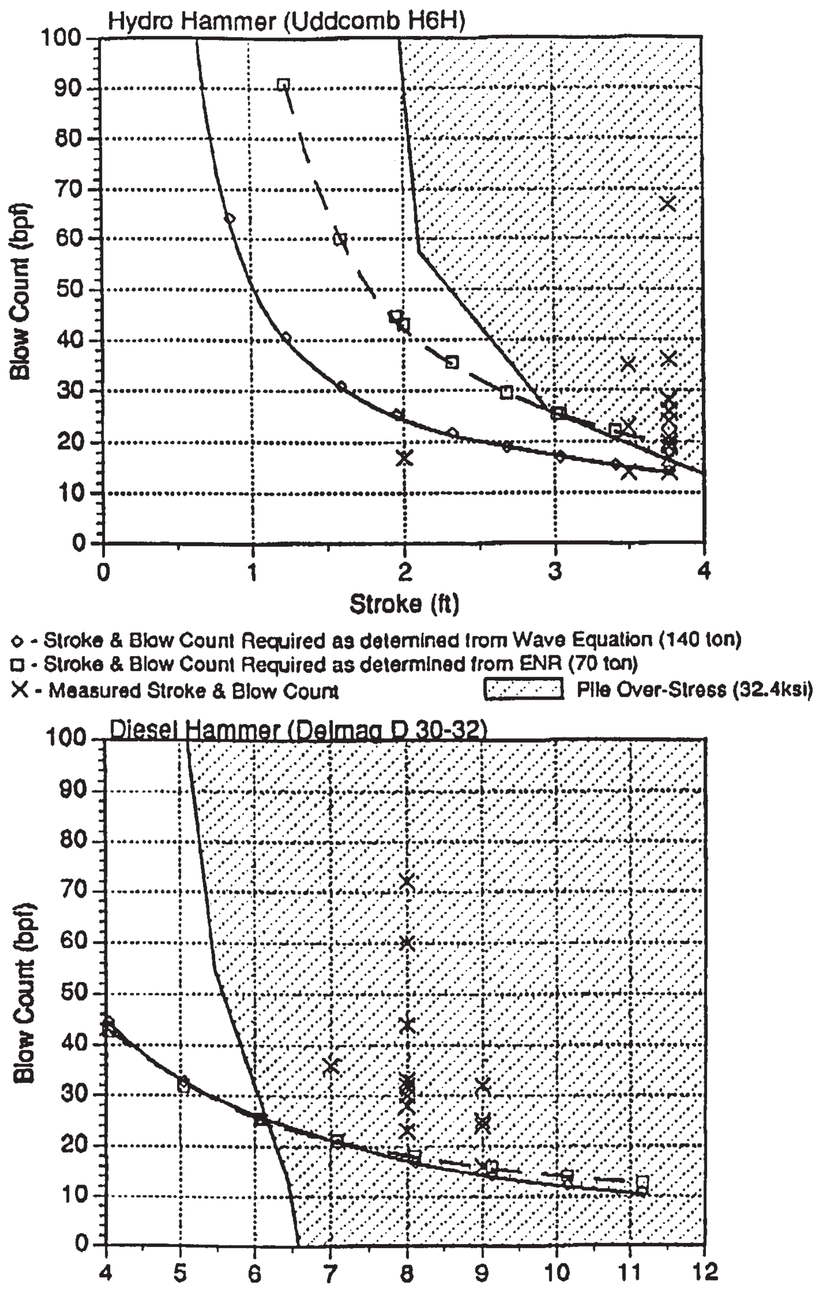


FIGURE 16-7 DESIGN DATA — EXAMPLE NO. 1



Example Wave Equation Field Acceptance Charts



Field Acceptance Charts for Hydro and Diesel Hammers
using both
Wave Equation Analysis and ENR formula
(HP12x84, L=32'±, Predrill = 22', Very Dense Boulders & Cobbles in Sand Matrix at tip, N>70)

Flow chart of Impact Pile Driving Hammers